

**EFFICIENCY, ENVIRONMENTAL CONTAMINANTS AND  
FARM SIZE: TESTING FOR LINKS USING STOCHASTIC  
PRODUCTION FRONTIERS**

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This paper investigates whether there is any relationship between farm size, technical efficiency and the use of agrochemicals which are potentially environmentally contaminating. These questions are pertinent in the context of current EU policy decisions. Using two models of stochastic frontier production and a set of panel data on 35 farms from the South West of England for the years 1987-1991, we obtain an indication, that there is a positive relationship between technical efficiency and use of contaminants, and between technical efficiency and farm size. However, there is a weak negative relationship between farm size and use of contaminants.

JEL classification: C23, C24, D24, Q12.

Keywords: Frontier production, technical efficiency, panel data, environment, farm size.

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\* The first author would like to thank Professor G.D.A. Phillips and the Head of the School of Business and Economics at City University Mr. Martin Timbrell for their continuous support. Both authors would like to thank T. Coelli from the University of New England, Australia, for kindly allowing us to use his software FRONTIER version 4.1, and the Agricultural Economics Unit at the University of Exeter for providing the data for this study, which originates from the firm Farm Business Survey conducted under the auspices of the UK Ministry of Agriculture, Fisheries and Food.

## **I. Introduction**

The question of whether efficiency levels differ between farms of different size in the European Union is pertinent following the 1992 reform of the Common Agricultural Policy which introduced, albeit in a limited way, modulated income support. For certain products, prices were reduced and income compensation payments offered on an area basis, with a bias in favor of the small producer. This set a precedent, which could have a bearing on future reforms of policy. Therefore the implications of the principle of small producer bias deserves examination. Whilst the provision of a higher level of income support, on a per hectare basis, to small producers may be appropriate for achieving social goals and limiting budgetary costs, it will impede structural change and thus stall the trend towards larger farms. Consequently, this paper investigates whether there is a potential loss in conventional resource efficiency from the adoption of a modulated income support policy, by estimating technical efficiency for farms of different size using stochastic production frontier estimation. Similar investigations have been conducted before (see below) although rarely with European data or with panel data, but this study is also distinct because it examines whether the usage of certain farm inputs, fertilizers and crop protection products, which are potential environmental contaminants, is linked to farm size and efficiency levels. This is a relevant area of inquiry given that EU policy makers are committed to consider the environmental consequences of their policies (Treaty of European Union, 1993). It is important to determine whether an income policy biased towards the small producer is in conflict with or complementary to environmental concerns.

Previous studies which have tested for links between farm size and efficiency have produced conflicting results. Whilst Lau and Yotopoulos (1973) and Trosper (1978) find evidence that small farms are the most efficient, Nehring et al. (1989), Bravo-Ureta and Rieger (1990) and Kumbhakar (1993) reach the opposite conclusion. Then Byrnes et al. (1987)

and Lund and Hill (1979) suggest that medium sizes farms are the most efficient, while Bagi (1982), Bagi and Huang (1983), Bravo-Ureta (1986) and Moussa and Jones (1991) are unable to establish any significant relationship between farm size and efficiency. Lack of consensus is perhaps unsurprising given that the studies were conducted with data from different countries and regions and reflect different production systems. Most focused on one particular commodity type of farm, and it is feasible that results could differ even within one region for different farm types. It may be inappropriate to generalize results too widely. Differences may also be explained by the use of different methodologies for measuring efficiency. Most studies were based on Farrell-type measures of technical efficiency (Farrell, 1957) relating to production frontiers, but others adopted a profit function or cost function approach. Even within production frontier studies a variety of methodologies were employed. However, Bravo-Ureta and Rieger (1990) found that when four types of frontier methodology were applied to the same data although this resulted in markedly different efficiency levels between farms, it did not lead to any significant difference in the ordinal ranking of farms.

In this paper two stochastic production frontier models are applied to panel data from 35 dairy farms in South West England for the five harvest years 1987/88 - 1991/92. The farms are classified as 'specialist dairy' and 'mainly dairy' and all output and most inputs are expressed in value terms. Two stochastic frontier production function models are explored. Both models are a linearized version of the logarithm of the Cobb-Douglas production function to which is added a random variable representing shocks outside the control of the farm. This random variable is assumed to be normally distributed. A second non-negative random variable (a truncated normal) is subtracted. This random variable represents technical inefficiency effects which are assumed to be controlled by the farm operator. The use of panel data permits examination of the stability of farm efficiency over time. In the first model technical inefficiency effects may vary monotonically over time. In the second model technical inefficiency effects depend on firm-specific variables and may vary non-monotonically over time.

Since 1984 the dairy industry in the UK has been subject to farm level quotas on milk production. The appropriateness of production frontier methodology when output is constrained has been questioned by Schmidt and Lovell (1979) and Dawson (1987). They contend that a profit maximization condition is necessary for production frontier estimation, whereas with production quotas imposed, producers are cost minimisers. But Russell and Young (1983) argue that profit maximization is not a necessary condition. In any case, since quotas are tradable and can be leased they are not necessarily a constraint at the farm level. Hence, in this study it is assumed that quotas are not binding. Battese and Coelli (1988) have also applied production frontiers to the dairy industry in Australia where farm level production quotas apply.

Changes in technology within agriculture have been biased towards using more purchased inputs, and the dairy sector has been no exception to this trend. These inputs have been significant in raising productivity but have also been responsible for environmental damage. In particular, the increased use of purchased variable inputs has contributed towards increasing levels of pollution. For example, fertilizer run-off can lower water quality, while pesticides can damage air quality and eliminate wildlife. It is often popularly assumed that production practices on small farms are less environmentally damaging than those on large farms. This view would seem to stem from a belief that small farms are less progressive and less commercially oriented. Indeed their small acreage might be the outcome of a lack of enterprise. Furthermore it is possible that small farms are owned by part-time farmers who may have objectives other than profit maximization. If it is true that small farms are more environmentally benign, then there is no conflict between a policy of modulated income support and environmental goals. However, in contrast it can be argued that those earning a living from a small acreage will use their limiting factor, land, intensively and therefore the environmental damage might be greater. Thus this study tentatively explores whether an empirical link between farm size and the use of inputs that cause

environmental pollution, can be identified. Fertilizers and chemical crop protection products are the two inputs that are defined as being potential environmental contaminants. It is recognised that there is not an exact correlation between the use of these inputs and environmental damage. Environmental damage will depend on both the management of the inputs and natural conditions such as soil type and climate. By focusing on dairy production in just one region of England the variation in natural conditions is at least limited. It is beyond the scope of this paper to determine the damage caused, it is merely argued here that the greater the use of these particular inputs, the greater the possibility of environmental damage.

The plan of the paper is as follows. Section II describes the two frontier production models used. In Section III the two models are applied to a set of panel data on 35 farms from the South West for the five harvest years 1987/88 - 1991/92. Conclusions are given in Section IV.

## II. Theoretical Models

The first model (model I) is a stochastic frontier production function model for panel data, in which technical inefficiencies of firms may vary monotonically over time (time-varying inefficiencies model). This model is described more thoroughly in Battese and Coelli (1992). The model may be expressed as:

$$Y_{it} = \sum_{j=1}^K x_{jit} \beta_j + (V_{it} - U_{it}), \quad (1)$$

and,

$$U_{it} = (U_i \exp(-\eta(t - T))) \quad i = 1, \dots, N, \quad t = 1, \dots, T, \quad (2)$$

where:

$Y_{it}$  is the logarithm of the production of the  $i$ -th farm in the  $t$ -th period;

$x_{jit}$  is the logarithm of the  $j$ -th input quantity of the  $i$ -th farm in the  $t$ -th period;

$\beta$  is a  $K \times 1$  vector of unknown parameters;

the  $V_{it}$  are random variables which are assumed to be iid  $N(0, \sigma_v^2)$ , and independent of the  $U_{it}$ ;

the  $U_{it}$  are non-negative random variables which are assumed to account for technical inefficiency in production and are assumed to be iid  $N(0, \sigma_u^2)$ .

The  $V_{it}$ 's represent the random variations in output due to factors outside the control of the farm operator (i.e. weather, topography, error of observations and measurement). The  $U_{it}$ 's account for factors which are under the control of the farm operator.

$\eta$  is a parameter to be estimated. This model is such that the non-negative technical inefficiencies effects,  $U_{it}$ , decrease, remain constant or increase as  $t$  increases, if  $\eta > 0$ ,  $\eta = 0$  or  $\eta < 0$ , respectively. Other more flexible specifications of behavior of the technical inefficiency effects over time are described in Battese and Coelli (1992).

The parameterization of Battese and Corra (1977) who replaced  $\sigma_v^2$  and  $\sigma_u^2$  with  $\sigma^2 = \sigma_v^2 + \sigma_u^2$  and  $\gamma = \sigma_u^2 / (\sigma_v^2 + \sigma_u^2)$  is followed.

The technical efficiency of a given farm (at a given time period) is defined by Battese and Coelli (1992) as the ratio of its mean production (conditional on its levels of factor inputs and firm effects) to the corresponding mean production if the firm utilized its levels of inputs most efficiently.

$$EFF_i = E[Y_i^* | U_i, X_i] / E[Y_i^* | U_i = 0, X_i] \quad (3)$$

$$= \exp(-U_i)$$

where,

$Y_i^* = \exp(Y_i)$ ; and

$EFF_i$  will take a value between zero and one.

The second model (model II) is analyzed in Battese and Coelli (1993). Here a stochastic frontier production function is defined for panel data on firms, in which the non-negative technical inefficiency effects are assumed to be a function of firm-specific variables and can vary non-monotonically over time. The technical inefficiency effects are assumed to be independently distributed as truncations of normal distributions with constant variance, but means which are a linear function of observable firm-specific variables. The firm-specific variables in inefficiencies stochastic frontier model for panel data is defined as above except for the term  $U_{it}$ . Here, the  $U_{it}$ 's are assumed to be independently distributed, such that  $U_{it}$  is obtained by truncation of the normal distribution with mean,  $z_{it}\delta$ , and variance,  $\sigma_U^2$ , more specifically;

$$U_{it} = z_{it}\delta + W_{it} \quad (4)$$

where,

$W_{it}$  is a truncation of the normal distribution with zero mean and variance  $\sigma_U^2$ .

$z_{it}$  is a (1 x m) vector of firm-specific variables which may vary over time; and

$\delta$  is an (m x 1) vector of unknown coefficients of the firm-specific inefficiency variables. The  $z_{it}$ -vectors may have the first element equal to one. They include some input variables involved in the production function and interactions between firm-specific variables and input variables.

It should be noted that model II is not a generalization of model I above. The two models are *not* nested.

### III. Empirical Applications

Empirical applications to the two models were made using a set of panel data for 35 farms, classified as 'mainly dairy', from the South West of England. The data collection was conducted by the Agricultural Economics Unit as part of the Farm Business Survey on the behalf of the UK Ministry of

Agriculture, Fisheries and Food. The data was collected according to value of output and cost of input, rather than in physical terms and therefore price indices were used to remove price change effects over time.

In the model I specification, technical inefficiency effects of the farms are permitted to vary systematically but monotonically with time.

The stochastic frontier production function estimated for model I is defined by

$$\begin{aligned} \log(\text{tout}_{it}) = & \beta_0 + \beta_1 \log(\text{labour}_{it}) + \beta_2 \log(\text{fs}_{it}) + \beta_3 \log(\text{mroc}_{it}) \\ & + \beta_4 \log(\text{contam}_{it}) + \beta_5 \log(\text{lscf}_{it}) + \beta_6 \log(\text{land}_{it}) \\ & + \beta_7 \text{pcland}_{it} + \beta_8 \text{year}_{it} + V_{it} - U_{it} \end{aligned} \quad (5)$$

where,

*tout* represents the total output from milk and crops;

*labour* represents the total costs of labor (family members and hired)

*fs* represents the total costs of feed and seeds;

*mroc* represents the total costs of maintenance, rates and overhead costs;

*contam* represents the total costs of fertilizer and crop protection products;

*lscf* represents the livestock capital flow;

*land* represents the total area (in hectares) of land;

*pcland* represents percentage of land devoted to non-forage crops;

*year* indicates the year of observation;

and  $V_{it}$  and  $U_{it}$  are the random variables whose distributional properties are defined in Section II.

The values of output and input costs are deflated by the appropriate price index. The year of observation is included in the model to account for technological change (Hicksian neutral) even though the time period considered is short. In addition, the percentage of land devoted to non-forage crops is included to allow for different rates of utilization of environmental contaminants on farms with a higher proportion of cereal crops.

The stochastic frontier model, defined by equation (5), contains eight



$b$ -parameters and the four additional parameters associated with the distributions of the  $V_{it}$  and  $U_{it}$ -random variables. Maximum-likelihood estimates for these parameters were obtained by using the computer program, FRONTIER version 4.1 written by Coelli (Coelli 1994). The frontier function (5) is estimated for five basic models:

Model I-1 involves all parameters being estimated;

Model I-2 assumes that  $\beta_\gamma = 0$ ;

Model I-3 assumes that  $\beta_\gamma = \mu = 0$ ;

Model I-4 assumes that  $\beta_\gamma = \eta = 0$ ;

Model I-5 assumes that  $\beta_\gamma = \mu = \eta = 0$ .

Empirical results for these five models are presented in table 1. Tests of hypotheses involving the parameters of the distribution of the  $U_{it}$ -random variables (farm effects) are obtained by using the generalized likelihood-ratio statistic. Several hypotheses are considered for different distributional assumptions and the corresponding statistics are presented in table 2. The specification of the stochastic frontier with time-varying farm-effects, with all parameters estimated, as in Model I-1, is traditional average production function. In this case it is not supported by the data.(i.e. the null hypothesis,  $H_0: \gamma = \mu = \eta = 0$ , is rejected). Further, the hypothesis that time-invariant model for farm effects applies is also rejected (i.e.,  $H_0: \eta = 0$ , is rejected). However, the hypothesis that the half-normal distribution is an adequate representation for the distribution of the farm effects is not rejected. Given that the half-normal distribution is assumed appropriate to define the distribution of the farm effects, the hypothesis that the yearly farm effects are time invariant is also rejected by the data. On the basis of these results it is evident that the hypothesis of time-invariant technical inefficiencies of farms in South-West England should be rejected. The selected model is therefore Model I-3, with half normal distribution and time varying farm effects. From this the technical efficiencies of the individual farms are calculated using the predictor given in equation (3). The values obtained,

**Table 1. Maximum-likelihood Estimates for Parameters of Stochastic Frontier Production Function for Farms using Model I**

Variable	Parameter	Model I-1	Model I-2	Model I-3	Model I-4	Model I-5
constant	$\beta_0$	2.16 (0.37)	2.15 (.36)	2.15 (0.36)	2.19 (0.37)	2.19 (0.38)
log(lab)	$\beta_1$	0.22 (0.05)	0.22 (0.05)	0.22 (0.04)	0.23 (0.05)	0.23 (0.05)
log(fs)	$\beta_2$	0.07 (0.03)	0.07 (0.03)	0.07 (0.03)	0.07 (0.03)	0.07 (0.03)
log(mroc)	$\beta_3$	0.20 (0.05)	0.20 (0.05)	0.20 (0.05)	0.20 (0.05)	0.20 (0.05)
log(contam)	$\beta_4$	0.10 (0.03)	0.10 (0.03)	0.10 (0.03)	0.10 (0.03)	0.10 (0.03)
log(lscf)	$\beta_5$	0.33 (0.05)	0.33 (0.05)	0.33 (0.05)	0.32 (0.05)	0.32 (0.05)
log(land)	$\beta_6$	0.08 (0.05)	0.09 (0.04)	0.09 (0.04)	0.09 (0.05)	0.09 (0.05)
pcland	$\beta_7$	0.0003 (0.001)	0	0	0	0
year	$\beta_8$	0.01 (0.006)	0.01 (0.006)	0.01 (0.006)	0.002 (0.004)	0.002 (0.004)
$\sigma^2 = \sigma_v^2 + \sigma_u^2$		0.06 (0.04)	0.06 (0.04)	0.06 (0.02)	0.05 (0.03)	0.05 (0.01)
$\gamma = \sigma_u^2 / \sigma^2$		0.93 (0.05)	0.93 (0.05)	0.93 (0.02)	0.91 (0.06)	0.91 (0.03)
$\mu$		0.0002 (0.21)	-0.005 (0.22)	0	-0.01 (0.21)	0
$\eta$		-0.06 (0.03)	-0.06 (0.03)	-0.06 0.03	0	0
Log (likelihood)		186.37	186.33	186.33	184.24	184.24

**Table 2. Tests of Hypothesis for Parameters of Distribution of the Farm Effects,  $U_{it}$ . Stochastic Frontier Production Function Model I**

Assumptions	Null Hypothesis $H_0$	$X^2$ -statistic	$\chi^2_{0.05}$	Decision
Model I-2	$\gamma = \mu = \eta = 0$	116	7.81	reject $H_0$
Model I-2	$\mu = 0$	$\approx 0$	3.84	accept $H_0$
Model I-2	$\eta = 0$	4.2	3.84	reject $H_0$
Model I-3 ( $\mu = 0$ )	$\gamma = \eta = 0$	186	5.99	reject $H_0$
	$\eta = 0$	4.2	3.84	reject $H_0$

together with the estimated mean technical efficiencies as defined by equation (6) in Battese and Coelli (1992) are given in table 3.

The technical efficiencies range between 0.618 and 0.977 in 1987 and, between 0.549 and 0.971 in 1991. Because the estimate for the parameter,  $\eta$ , is negative ( $\hat{\eta} = -0.06$ ) the technical efficiencies decrease over time, according to model I. The estimated elasticities have all the right signs. The coefficient 0.01, of the variable, year of observation, in the estimated model I-3, implies that the value of output (in real terms) is estimated to have increased by 1 percent over the five year period for the farms in the South-West.

In the case of model II, the estimated stochastic frontier production function is defined by

$$\begin{aligned} \log(\text{tout}_{it}) = & \beta_0 + \beta_1 \log(\text{labour}_{it}) + \beta_2 \log(\text{fs}_{it}) + \beta_3 \log(\text{mroc}_{it}) \\ & + \beta_4 \log(\text{contam}_{it}) + \beta_5 \log(\text{lscf}_{it}) + \beta_6 \log(\text{land}_{it}) \\ & + \beta_7 \text{pcland}_{it} + \beta_8 \text{year}_{it} + V_{it} - U_{it} \end{aligned} \quad (6)$$

where the technical inefficiency effects are assumed to be defined by equation (7),

$$U_{it} = \delta_0 + \delta_1 (\text{land}_{it}) + \delta_2 (\text{year}_{it}) + \delta_3 (\text{contam}_{it}) + \delta_4 (\text{pcland}_{it}) + W_{it} \quad (7)$$

All the variables have been defined above.

**Table 3. Predicted Technical Efficiencies of Farms for the Years 1987-1991 using Model I**

Farm	1987	1988	1989	1990	1991
1	0.618	0.601	0.584	0.566	0.549
2	0.977	0.975	0.974	0.972	0.971
3	0.952	0.950	0.947	0.944	0.941
4	0.968	0.966	0.964	0.962	0.960
5	0.969	0.967	0.965	0.963	0.961
6	0.970	0.968	0.966	0.964	0.962
7	0.761	0.750	0.737	0.725	0.712
8	0.905	0.900	0.895	0.889	0.883
9	0.783	0.773	0.761	0.750	0.738
10	0.907	0.902	0.896	0.891	0.885
11	0.968	0.966	0.964	0.962	0.960
12	0.925	0.921	0.916	0.912	0.907
13	0.817	0.807	0.798	0.787	0.777
14	0.883	0.877	0.871	0.864	0.857
15	0.794	0.784	0.773	0.762	0.750
16	0.953	0.951	0.948	0.945	0.942
17	0.791	0.780	0.769	0.758	0.746
18	0.742	0.729	0.716	0.703	0.689
19	0.972	0.970	0.969	0.967	0.952
20	0.832	0.823	0.814	0.805	0.795
21	0.798	0.797	0.777	0.766	0.754
22	0.849	0.841	0.833	0.825	0.816
23	0.977	0.976	0.974	0.973	0.971
24	0.844	0.836	0.827	0.819	0.809
25	0.761	0.750	0.738	0.725	0.712
26	0.817	0.808	0.798	0.788	0.777
27	0.947	0.944	0.941	0.938	0.934
28	0.963	0.961	0.959	0.956	0.954
29	0.779	0.768	0.757	0.745	0.732
30	0.967	0.965	0.963	0.961	0.959
31	0.977	0.976	0.974	0.973	0.971
32	0.819	0.810	0.800	0.790	0.780
33	0.849	0.841	0.833	0.825	0.816
34	0.791	0.780	0.770	0.758	0.747
35	0.926	0.818	0.808	0.799	0.789
Mean	0.870	0.863	0.857	0.849	0.842

As in model I, equation (6) can be viewed as a linearized version of the logarithm of the Cobb-Douglas production function. Here technical inefficiency effects are assumed to be present in the stochastic frontier and be linearly related to land, year of observation, fertilizer and crops protection and the proportion of land under crops. An intercept term is included. The firm-specific variables in inefficiencies stochastic frontier model, defined by equation (6) and (7), account for both technical change and time-varying technical inefficiency effects. The *year* variable in the stochastic frontier production function (6) accounts for Hicksian neutral technological change. However, the *year* variable in the inefficiency model (7) specifies that the technical inefficiency effects may change linearly with respect to time.

Maximum-likelihood estimates of the parameters of the model, defined by equations (6) and (7) were obtained using the computer program, FRONTIER version 4.1 (see Coelli, 1994). These results are given in table 4. Using generalized likelihood-ratio tests Model II-2 seems to be the best specification for our data, with the signs of all the  $\beta$  - estimates as expected.

The coefficients of the explanatory variables in the inefficiency model (7) are of particular interest to this analysis. The estimate for the coefficient associated with *land* is negative, which indicates that larger farms are more efficient than the smaller ones. The estimate for the coefficient associated with the use of *potential environmental contaminants* is also negative. This suggests that the more efficient farms use more fertilizers and crop protection products. The positive sign of the year variable implies that technical inefficiency of production went up during the five years.

Generalized likelihood-ratio tests of the hypotheses that the technical inefficiency effects are absent or that they have simpler distributions are presented in table 5.

The null hypothesis that the technical inefficiency effects are absent from the model (i.e.,  $H_0: \gamma = \delta_0 = \delta_1 = \delta_2 = \delta_3 = 0$ ) is rejected. The second null hypothesis that the technical inefficiency effects are not a linear function of the *land*, *year*, and *contaminants* (i.e.,  $H_0: \delta_0 = \delta_1 = \delta_2 = \delta_3 = 0$ ) is also rejected.

**Table 4. Maximum-likelihood Estimates for Parameters of Stochastic Frontier Production Function for Farms using Model II**

Variable	Parameter	Model I-1	Model I-2	Model I-3	Model I-4
constant	$\beta_0$	2.21 (0.39)	2.26 (0.24)	1.2 (0.23)	1.18 (0.25)
log(lab)	$\beta_1$	0.11 (0.05)	0.12 (0.04)	0.13 (0.04)	0.13 (0.04)
log(fs)	$\beta_2$	0.22 (0.03)	0.22 (0.02)	0.22 (0.02)	0.22 (0.03)
log(mroc)	$\beta_3$	0.29 (0.05)	0.31 (0.05)	0.27 (0.05)	0.27 (0.05)
log(contam)	$\beta_4$	0.05 (0.06)	0.04 (0.03)	0.08 (0.03)	0.08 (0.03)
log(lscf)	$\beta_5$	0.24 (0.06)	0.24 (0.05)	0.35 (0.05)	0.36 (0.05)
log(land)	$\beta_6$	0.03 (0.06)	0	0	0
pcland	$\beta_7$	-0.0009 (0.001)	0	0	0
year	$\beta_8$	-0.003 (0.009)	0	0	0
constant	$\delta_0$	0.37 (0.12)	0.39 (0.07)	0	-0.1 (0.4)
land	$\delta_1$	-0.004 (0.003)	-0.004 (0.001)	0	0
year	$\delta_2$	0.005 (0.02)	0.01 (0.01)	0	0
contam	$\delta_3$	-0.00002 (0.00003)	-0.00003 (0.00001)	0	0
pcland	$\delta_4$	-0.003 (0.005)	0	0	0
	$\sigma_s^2$	0.03 (0.005)	0.02 (0.004)	0.03 (0.005)	0.04 (0.04)
	$\gamma$	0.75 (0.08)	0.72 (0.04)	0.88 (0.06)	0.89 (0.06)
Log (likelihood)		138.44	138.19	132.28	132.34

**Table 5. Tests of Hypothesis for Parameters of the Inefficiency Stochastic Frontier Production Function Model II**

Assumptions	Null Hypothesis $H_0$	$\chi^2$ -statistic	Decision
Model II-1	$\beta_6 = \beta_7 = \beta_8 = \delta_4 = 0$	$\approx 0$	accept $H_0$
Model II-2	$\gamma = \delta_0 = \delta_1 = \delta_2 = \delta_3 = 0$	23.7	reject $H_0$
	$\delta_1 = \delta_2 = \delta_3 = 0$	11.7	reject $H_0$

This indicates that the joint effects of these three explanatory variables on the levels of technical inefficiencies is significant.

The parameter estimates for the selected stochastic frontier production function (model II-2) indicate that the elasticity for *labour*, *mroc*, *contam*, and *lscf* are relatively important, respectively 0.22, 0.20, 0.10, and 0.33. whereas, the estimated elasticity for other inputs, *fs*, *land* and *year* are relatively small, respectively 0.07, 0.09, 0.01, but significantly different from zero. These estimates imply that the returns-to-scale parameter is estimated to be around one. The same result has been obtained for model I-3, the selected model. Thus the technology of the South-West farm is such that the hypothesis of constant returns to scale would be accepted.

The technical inefficiency effects in the selected model are significant. Technical inefficiency effects tend to decrease with farm size and use of contaminants. But, the levels of technical inefficiency effects for farms in the South-West tend to increase over time.

The predicted technical efficiencies obtained for the 35 farms are presented in table 6.

The predicted technical efficiencies for Model II exhibit less variability both among farms and over time than in Model I. As the two models are not nested, the logarithm of likelihood function and AIC were used to find the “best” model. Both criteria point to Model I-3 as being a “better” model than model II-2 but no definite conclusion can be drawn from these two criteria. Model I which impose a monotonic variation of technical efficiency over time is in some sense favored by the use of these two criteria.

**Table 6. Predicted Technical Efficiencies of Farms for the Years 1987-1991 using Model II**

Farm	1987	1988	1989	1990	1991
1	0.754	0.635	0.645	0.646	0.693
2	0.957	0.961	0.939	0.955	0.948
3	0.891	0.956	0.901	0.858	0.912
4	0.864	0.930	0.831	0.919	0.912
5	0.856	0.884	0.826	0.864	0.900
6	0.981	0.983	0.980	0.983	0.983
7	0.733	0.701	0.663	0.691	0.688
8	0.985	0.988	0.984	0.980	0.986
9	0.981	0.978	0.973	0.984	0.979
10	0.942	0.952	0.914	0.940	0.929
11	0.962	0.982	0.979	0.972	0.971
12	0.907	0.939	0.928	0.891	0.923
13	0.859	0.818	0.839	0.859	0.794
14	0.934	0.901	0.860	0.883	0.831
15	0.978	0.984	0.976	0.980	0.983
16	0.914	0.939	0.930	0.940	0.911
17	0.769	0.804	0.755	0.739	0.771
18	0.818	0.761	0.796	0.796	0.795
19	0.933	0.958	0.957	0.958	0.957
20	0.934	0.940	0.928	0.906	0.927
21	0.914	0.906	0.816	0.904	0.903
22	0.881	0.813	0.596	0.909	0.826
23	0.955	0.968	0.974	0.971	0.966
24	0.858	0.853	0.929	0.945	0.900
25	0.799	0.895	0.773	0.813	0.822
26	0.864	0.885	0.852	0.879	0.854
27	0.958	0.939	0.931	0.947	0.952
28	0.920	0.966	0.972	0.965	0.942
29	0.800	0.852	0.705	0.801	0.790
30	0.970	0.977	0.983	0.973	0.979
31	0.977	0.981	0.974	0.978	0.963
32	0.922	0.929	0.889	0.868	0.895
33	0.923	0.860	0.893	0.960	0.956
34	0.949	0.908	0.952	0.850	0.886
35	0.864	0.811	0.806	0.793	0.865
Mean			0.893		



For Model I the correlation coefficient between technical efficiency and use of potential environmental contaminants per hectare is 0.22 and it is equal to 0.16 between technical efficiency and farm size. For model II the correlation coefficients are respectively equal to 0.19 and 0.64. However, although both use of contaminants and farm size are positively related to efficiency levels, the correlation coefficient between contaminants and size is negligible with a negative sign.

#### **IV. Conclusions**

This study has measured farm efficiency using panel data which has permitted the testing of time variant effects. Model I imposes monotonic variation, but Model II is more flexible and permits non-monotonic variation, and also relates technical efficiency effects to chosen parameters.

Both models indicated that technical efficiency had fallen over the five year time period, whilst Model II also established that the more efficient farms were larger farms and used a higher volume of environmental contaminants. The results indicated that technical efficiency improves as farm size increases, and is associated with greater use of environmental contaminants. This was enforced with correlation tests on both models, yet the correlation between farm size and environmental contaminants was found to be weak.

Although Model II would appear to be a more general model than Model I, the two in fact, are not nested. Two criteria were used to test for the better model. There was some indication that Model I provides a better explanation of the data, however, the two criteria are not conclusive.

The results give some support to the argument that inhibiting structural change through giving greater financial support to operators of smaller farms may incur a resource efficiency cost. This does not imply that such a measure should not be implemented on equity grounds, but simply highlights that there is a cost involved. Finally, the lack of correlation between the use of

contaminants and farm size, provides no support to the case that small farms are more environmentally benign.

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